(12) UK Patent Application (19) GB (11) 2 287 792 (13) A

(43) Date of A Publication 27.09.1995

(21) Application No 9505706.3

(22) Date of Filing 21.03.1995

(30) Priority Data
(31) 9406018 (32) 25.03.1994 (33) GB

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(51) INT CL[6]
G01P 5/18, G01F 1/704

(52) UK CL (Edition N)
G1N NACDT N1A2C N1A2P N1D13 N1D4 N3S2 N7A1 N7B1 N7B2
U1S S1259 S1451

(56) Documents Cited
GB 1422685 A WO 94/15180 A1

(58) Field of Search
UK CL (Edition N) G1N NACDT NAEQ
INT CL[6] G01F 1/704 1/708, G01P 5/10 5/12 5/18
Online:WPI

(54) Method and devices for measurement of flow speed using continuous oscillations in a thermal wave

(57) Flow speed is derived from the continuous oscillation frequency of a system comprising a temperature sensor 4 situated downstream of and in the thermal wake of an electric heater 3 in the flowing fluid. The output signal from the sensor 4 is processed by electronic means 5 which provides power to energise the heater. The oscillating circuit is completed by the travelling thermal wave in the fluid downstream of the heater. Arrangements also indicating flow direction and providing temperature compensatiion are described.

The invention may be used to measure flow in pipes over a wide range of flow speeds and is suited for use in measuring very small flows with high accuracy. Wind speed may also be measured.

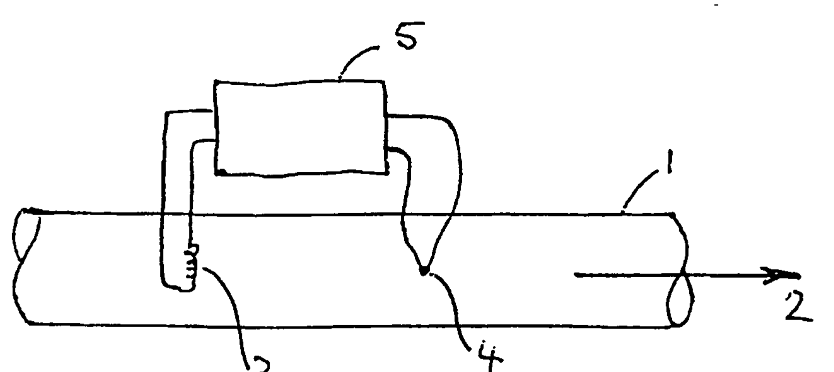

Figure 3

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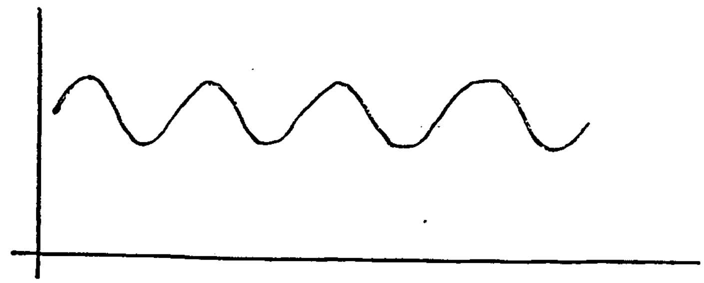

Figure 1

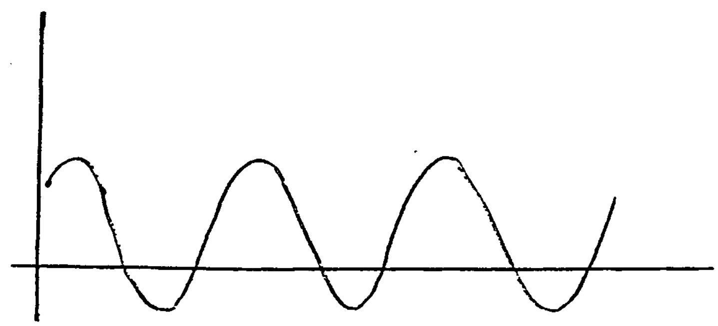

Figure 2

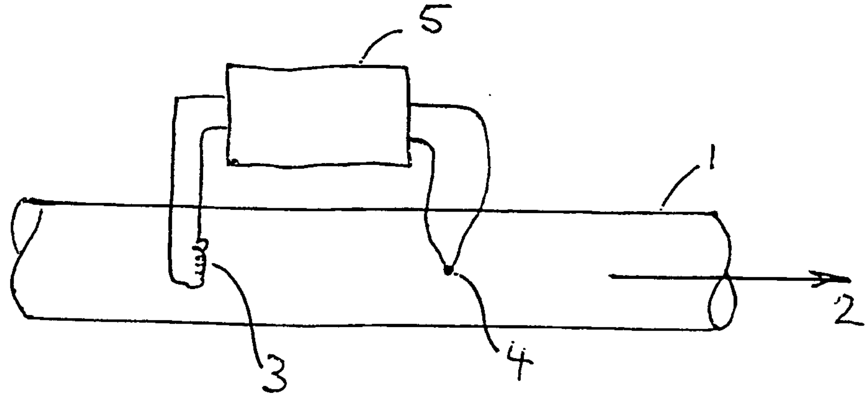

Figure 3

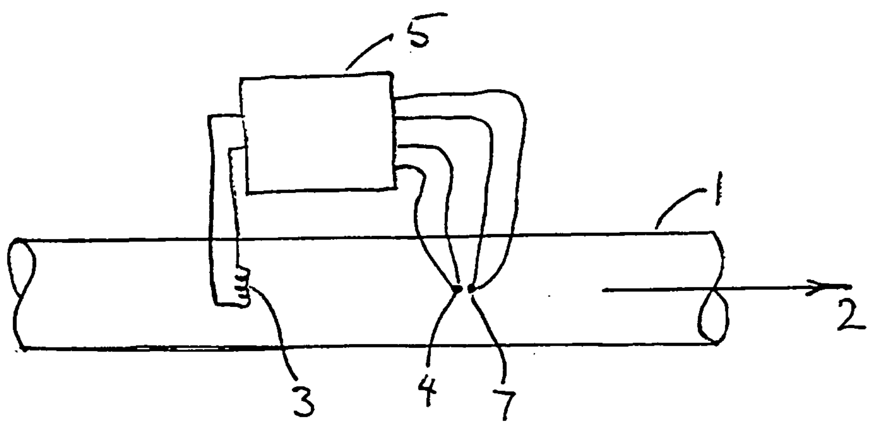

Figure 4

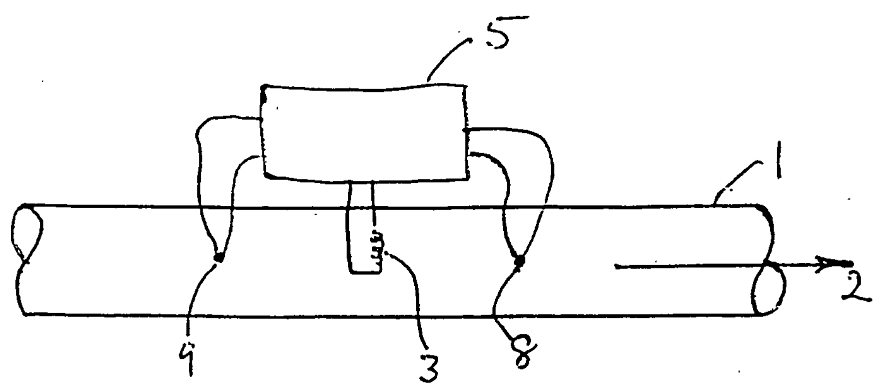

Figure 5

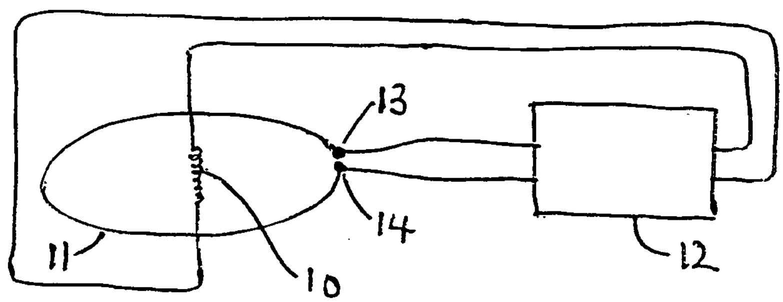

Figure 6

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METHOD AND DEVICES FOR MEASUREMENT OF FLOW SPEED USING CONTINUOUS OSCILLATIONS IN A THERMAL WAVE

The present invention relates to a method for measuring the flow speed of fluids.

The invention is concerned with recognition of the facts that if heat is transferred sinusoidally over time to a flowing fluid from a heat source immersed in the fluid then temperature fluctuations occur in the heated wake downstream of the source, and that if the output from an electrical temperature sensor sited downstream of an electric heater immersed in the flowing fluid is suitably processed and connected to the heater then the system can exhibit continuous self sustaining oscillation the frequency of which is related to the flow speed of the fluid. The flow velocity of the fluid can thus be derived from measurement of the frequency of oscillation of the system. In the case of confined flows, for example flow in a pipe, the oscillation frequency also gives an indication of the volumetric flow rate. The method of the invention is applicable to flows of liquids and gasses. It is believed that the frequency of oscillation of a system involving the travelling thermal wave downstream of a heater has not previously been proposed as a method for the measurement of the flow speed of fluids.

Very many devices already exist for the measurement of fluid flow speed and, in the case of confined flows, of volume flow rate. Such devices generally fall into one of the following categories:
(1) Kinetic energy devices wherein the local flow velocity is modified by an obstruction and the resulting change in the kinetic energy of the flowing fluid is measured in terms of a pressure change. Venturi tubes, orifice plate meters and Pitot tubes are in this category. Kinetic energy devices all have the inherent feature that in order to infer fluid velocity from the pressure measurements it is necessary that the density of the fluid be known. These devices thus have calibrations which are fluid-dependant which is a disadvantage in practice since they cannot be used in applications where the nature of the fluid is unknown or is likely to vary. Kinetic energy devices have approximately square-law calibration curves and thus have comparatively poor sensitivity at low flow rates.
(2) Acoustic devices in which the propagation velocity of an acoustic pulse is measured by timing over a known distance. The measured velocity is the sum of the propagation velocity in stationary fluid and the

fluid flow velocity and so the calibrations of these devices are fluid-dependent which is a disadvantage.

(3) Thermal anemometers in which the fluid flow velocity is inferred from the rate of heat transfer from a heated body immersed in the flow. The heat transfer rate is dependent on the local fluid velocity and also on the thermal properties of the fluid. Thus these devices have the disadvantage of fluid-dependent calibrations. In addition, the calibrations of these devices are affected by accidental contamination of the surface of the heated body.

(4) Mechanical devices such as gap meters and turbines which have the disadvantage of fluid-dependent calibrations. They also impose significant energy losses on the flow which may be undesirable.

(5) Time-of-flight devices in which a small volume of the flowing fluid is labelled in some way and the speed of the labelled packet is inferred from timing its progress downstream. Labelling can be achieved by the injection into the flow of, for example, dye or bubbles in the case of liquid flows or thermal labelling may be used for flows of liquids or gasses. Time-of-flight devices have the advantage over the other devices mentioned above of giving a direct indication of flow velocity; in principle they can be used to measure the flow speed of fluids of unknown composition. Typically these devices involve complicated dosing apparatus which is a disadvantage or the addition of heat to the flow using electrical heaters which are undesirable in the case of flows of flammable fluids. Also the distance over which timings are taken may need to be inconveniently large in order to faithfully indicate the mean flow speed.

The principal object of the present invention is to provide a device for, and a method of, determining the speed of flow of a liquid or gas which is relatively simple and compact and hence cheap to manufacture, and which mitigates if not overcomes many of the disadvantages discussed above of the known devices.

A particular feature of the present invention is that devices based on it give a measurement of actual flow velocity and can thus be used to measure flows of any liquid or gas without the need for recalibration.

A device according to the present invention could be readily installed in an existing pipe through a hole made in the pipe wall. Because of the small size of devices according to the invention the size of the hole to be made in the pipe wall need be only about 10 millimetres

diameter for large pipes and for small pipes could be correspondingly less. Alternatively, the device could be provided inside a length of pipe furnished with connections at each end and could then form a direct replacement for other types of flowmeters. Devices according to the invention may be constructed in the form of a probe which could be used, for example, to map the flow velocity inside a duct.

Devices according to the invention could be manufactured entirely from inert materials, for example platinum and P.T.F.E., and could thus be used in corrosive environments. The devices could withstand autoclave temperatures and would thus be suitable for use in medical applications where sterility is a requirement.

The electrical power dissipation of the devices can be sufficiently small that they can safely be used to measure flows of flammable liquids and gasses. In some preliminary experiments power levels of about 20 mW applied to the heater were found to be sufficient for satisfactory operation, and it is likely that this power requirement can be substantially reduced.

Tests have shown that devices according to the invention can be used to measure very small flow rates in pipes. Flows of air, propane and carbon dioxide in a 9 mm pipe have been measured satisfactorily when the volume flow rate was less than 1 ml/s. Devices according to the invention would thus be suitable for gas flow measurement in, for example, anaesthetic apparatus, semiconductor manufacture, gas chromatography, and the like; they are also particularly suitable for the measurement of the small gas flows of unpredictable composition from landfill sites in which gas production is nearly completed.

According to the present invention there is provided a device for determining the speed of a flowing fluid comprising a resistive heater, at least one temperature sensing device, means to modify the output signal from at least one temperature sensor, means to measure the frequency of oscillation and means to indicate the direction of flow.

It will be appreciated that the heater and temperature sensors may be physically small, they could, for example, be formed of wire of diameter 20 microns or less, and thus the resistance to flow caused by the heater and sensors could be practically negligible.

Before describing certain embodiments of the invention, a brief description of the physics underlying the invention will be given. Reference will be made to Figures 1 and 2 of the accompanying drawings, which are graphical representations of voltage waveforms in which the vertical axis represents voltage and the horizontal axis represents time.

If a voltage having a cyclically varying component, for example a sinusoidal component as depicted in Figure 1, is applied to a resistive heating element immersed in a flowing fluid, then the power dissipated gives rise to heat production, and the surface temperature of the heater initially increases above the ambient temperature of the fluid. Heat is carried away from the heater by the fluid flowing over its surface and a steady state is eventually reached wherein the mean temperature of the heater and the mean temperature field in the heated wake downstream of it become independent of time. The amount by which the mean temperature of the wake exceeds the ambient temperature of flowing fluid decreases with distance downstream of the heater because of diffusion, and far downstream of the heater the temperature difference is practically undetectable. The surface temperature of the heater fluctuates at a fundamental frequency equal to that of the fluctuating component of the applied voltage. The waveform of the surface temperature fluctuations lags somewhat behind the heater voltage waveform. This temporal lag may be described in terms of a phase angle. The magnitude of the phase angle depends on frequency and also on the thermal time-constant of the heater. In the case of a heater having a large thermal capacity the phase lag could be substantial, but would necessarily be less than ninety degrees. On the other hand, if the heater were, for example, made from very thin wire then the phase angle could be small.

The wake downstream of the heater is a travelling thermal wave in which the temperature at a fixed position fluctuates at a fundamental frequency equal to the frequency of the voltage fluctuations applied to the heater. Because the heated fluid in the wake moves downstream at the fluid flow speed the spatial wavelength, λ, of the temperature fluctuations in it is given by $\lambda = U / f$, where **U** is the flow speed and **f** is the frequency of the fluctuating voltage applied to the heater.

It will be apparent from the foregoing description that the temperature waveform at a point distant **d** downstream of the effective centre of the heater lags the heater voltage waveform by an angle

$\phi_h + \phi_d$ where ϕ_h is the phase lag angle due to the thermal capacity of the heater and ϕ_d owes to the distance of the observation point downstream from the heater. The phase angle ϕ_d , expressed in degrees, is given by the formulas

$$\phi_d = 360\ d / \lambda$$

$$\text{and} \quad \phi_d = 360\ d\ f / U \quad ,$$

where the symbols have the same meaning as before.

If a temperature sensor capable of giving an electrical output, for example a thermocouple, were sited in the heated wake at a distance **d** downstream of the effective centre of the heater then the output waveform from the sensor would lag behind the temperature waveform of the flowing fluid at the position of the sensor by a phase angle ϕ_s due to the thermal capacity of the sensor. The magnitude of the phase angle ϕ_s depends upon the frequency of the temperature fluctuations and also on the thermal time-constant of the sensor.

The total phase lag, ϕ , between the voltage waveform applied to the heater and the output waveform of the sensor is thus

$$\phi = \phi_h + \phi_d + \phi_s \quad .$$

If the heater and sensor have a sufficiently small thermal capacities that ϕ_h and ϕ_s are small compared with ϕ_d then ϕ would be approximately equal to **360 d f / U** degrees.

If the output from the temperature sensor is connected through electronic circuitry to the heater then a closed loop is formed the components of which are the temperature sensor, the electronic circuitry, the heater and the travelling temperature wave in the flowing fluid. Oscillations are possible in this closed loop system under certain circumstances which are considered below by analogy with a purely electronic oscillator.

As is well known, the so-called phase shift electronic oscillator consists of an inverting amplifier the output of which is connected through a suitable reactive network of components to its own input. Oscillation is possible at a frequency which produces a phase shift of 180

degrees across the network. For oscillation to occur it is necessary that the gain of the amplifier should be sufficient to overcome the attenuation of the network at the frequency of oscillation. Phase shift oscillators are self starting and in practice need to embody means to limit the amplitude of oscillation which were it allowed to become too large would, in practical circuits, lead to distortion of the sinusoidal waveform of the oscillation.

The closed loop system incorporating the travelling temperature wave in a flowing fluid can oscillate approximately sinusoidally provided the gain of the electronic circuitry in the loop exceeds the attenuation ratio between the fluctuating parts of the voltage applied to the heater and the voltage output from the sensor. It is also necessary that the circuitry should provide output at a suitable mean level and should include means for limiting the amplitude of the oscillations. The frequency of oscillation would be that at which $\phi + \phi_e = 360$ degrees, where ϕ_e is the phase angle by which the output of the electronic circuit lags behind its input signal.

It has been shown that provided the phase angles associated with the heater and sensor are sufficiently small, the phase angle ϕ would be approximately $\mathbf{360\ f\ d\ /\ U}$ degrees. Under these circumstances, if the electronic circuit were a simple inverting amplifier for which $\phi_e = \mathbf{180}$ degrees then it will be appreciated that the frequency of oscillation would be given by $\mathbf{f = U\ /\ 2\ d}$ approximately.

Thus, according to the theory outlined above, it appears that an apparatus in which the distance **d** was known to sufficient accuracy could give a good indication of flow speed derived from observation of its oscillation frequency. In some practical applications of this method it might happen that the phase shift angles associated with the heater and the sensor are not negligibly small, or that the distance of the sensor downstream of the effective centre or the heater is not known to good enough accuracy or that the phase shift introduced by the electronic circuit is frequency dependent; the relationship between oscillation frequency and flow speed would then have to be determined empirically.

In a known existing publication (Juffa et al, 1980, U.S. Patent 4228683) a method of flow measurement is described in which a heater situated in a flowing fluid is energised for a short time by the discharge through it of a capacitor. The compact so-called slug of heated fluid

produced is later detected downstream by a temperature sensor, and the time interval between the initiation of the capacitor discharge and the arrival of the heated fluid at the sensor is used to calculate the flow speed. The flow speed obtained in this way is thus based on a measurement of the time-of-flight of the heated slug of fluid. In a refinement of this technique, Juffa caused the arrival of the heated slug at the sensor to trigger the discharge of the capacitor into the heater. The process was thus repetitive, and the frequency of the capacitor discharges was used to deduce the average of a number of times-of-flight and hence the flow speed.

We assert a fundamental difference between the repetitive version of the Juffa invention and the method being described in the present Application. It will be appreciated that according to the present invention information is continuously conveyed from the heater to the sensor by the travelling thermal wave in which temperature varies continuously in time and space, whereas in the Juffa invention the feature of continuous variation of temperature downstream of the heater is absent, and information reaches the sensor in the form of discrete temperature pulses separated by intervals during which no relevant information is received by the sensor.

If the sinusoidally varying voltage depicted in Figure 1 is applied to a resistor the power fluctuations in it are composed of oscillations at the frequency of the applied voltage and a component oscillating at twice this frequency. The second harmonic component owes to the fact that the power is proportional to the square of the applied voltage. If the mean voltage is progressively reduced while keeping the amplitude of the fluctuating part constant then the amplitude of power fluctuations at the fundamental frequency also reduce whilst the amplitude of the second harmonic power oscillations are unaltered. If the mean voltage level is reduced to zero then power oscillations at the frequency of the applied voltage disappear and all power fluctuations are at twice this frequency. Owing to their thermal capacities, heaters and sensors behave as low-pass thermal filters and it would be expected that the second harmonic content of sensor output would be substantially less than the second harmonic content of power fluctuations in the heater. Experiments in which the voltage waveform from a signal generator as depicted in Figure 2 was applied to a heater immersed in an air flow have borne out this expectation. The amplified output from a downstream thermocouple was

seen to be closely sinusoidal, although the second harmonic content of the power fluctuations in the heater would have been substantial.

Thus, a first aspect of the invention provides a method of measuring the flow velocity of a fluid comprising an electric resistance heater, an electrical temperature sensor situated downstream of the heater, an electronic circuit to amplify the signal from the sensor the output of which is arranged to provide a substantially non-symmetric voltage waveform of stable amplitude which is connected to the heater and means to measure the frequency of oscillation.

Experiments carried out in an air flow have shown that oscillation occurs when the cyclic voltage variations applied to the heater are non-sinusoidal, and square waveforms applied to the heater have been found to work equally as well as a sinusoidal voltage waveform. Under these circumstances the sensor output is approximately sinusoidal due to the filtering effects of the heater and the sensor. Connection of the sensor output signal to a suitable comparator produces a square waveform for connection to the heater. The use of a square waveform derived from a comparator obviates the need to control the amplitude of the oscillations, and the simplification of the electronic circuitry yields savings in cost.

Thus, a second aspect of the invention provides a method of measuring the flow velocity of a fluid comprising an electric resistance heater, an electrical temperature sensor situated downstream of the heater, means to produce a square voltage waveform of suitable mean level which is connected to the heater and means to measure the frequency of oscillation.

It has been mentioned that it may be desirable to employ a heater of very small thermal mass such as a short length of thin wire which would probably have a rather small resistance, possibly only a fraction of one ohm, and such a heater could require the use of an inconveniently small voltage and possibly also an inconveniently large heater current. It may not be feasible to couple the fluctuating output of the electronic circuit to the heater using a transformer because the frequency of oscillation could be rather low when the speed of the flow being measured is small. This difficulty may be overcome by arranging for amplitude modulation of a high frequency carrier to be effected by the signal derived from the sensor. Because the carrier frequency can be relatively high, for

example in the kilohertz range, power could be transferred into the low resistance heater using a small transformer.

Thus a third aspect of the invention provides a method of measuring fluid flow comprising an electric resistance heater, an electrical temperature sensor situated downstream of the heater, means to produce stable amplitude modulation of a relatively high frequency carrier wave by the output signal from the sensor, a transformer to couple the modulated carrier to the heater and means to measure the frequency of oscillation of the sensor output signal.

It will be appreciated that if a square voltage waveform of zero mean level is applied to a resistive heater then no power fluctuations occur, and that any other symmetric waveform having zero mean level gives rise to power fluctuations in the heater having a fundamental frequency equal to twice the fundamental frequency of the waveform applied to the heater. Thus if a non-square voltage waveform, for example a sine wave, were applied to a heater in a flowing fluid the output signal from a downstream temperature sensor would fluctuate approximately sinusoidally at twice the frequency of the voltage applied to the heater. The frequency of the sensor signal could conveniently be halved using a bistable multivibrator thus giving a square wave of the same frequency as the voltage waveform applied to the heater. It would be necessary to modify the square shape of the multivibrator output before it is applied to the heater in order that power fluctuations should occur in the heater. Modification of the waveform shape could conveniently be effected using a low-pass filter circuit. An advantage of the arrangement just described is that it ensures that the duty-cycle of the square waveform is 50%.

Thus, a fourth aspect of the invention provides a method of measuring fluid flow comprising an electrical resistance heater, an electrical temperature sensor situated downstream of the heater, means to halve the frequency of the signal from the sensor and to modify the waveform shape of the halved frequency signal connected to the heater and means to measure the frequency of oscillation.

It has been shown that the oscillation frequency of devices according to the invention depends on the fluid flow speed and also on the distance of the temperature sensor from the heater. Small flow speeds give rise to low oscillation frequencies which may be a disadvantage; this disadvantage may be overcome by providing a plurality of temperature sensors situated

at various distances from the heater, and arranging for the electronic circuit to take input from a sensor which produces a suitable oscillation frequency. Selection of the sensor to provide input to the electronic circuit could be effected by manual switching or could be controlled by a computer. for simplicity the plurality of sensors described here is not illustrated in the accompanying drawings.

Certain specific embodiments of devices and methods the present invention will now be described by way of example only and by reference to the accompanying drawings, in which:

Figure 3 is a schematic diagram of a first embodiment of apparatus according to the invention for the measurement of flow in a pipe;

Figure 4 is a schematic diagram of a preferred form of apparatus embodying temperature compensation;

Figure 5 is a schematic diagram of an especially preferred form of apparatus including indication of flow direction;

Figure 6 is a perspective view of a second embodiment of apparatus according to the invention for the measurement of wind speed.

A first embodiment of the invention will now be described with reference to Figure 3. The illustrated apparatus is intended for measuring the fluid flow in a pipe, 1, in the direction of the arrow, 2. The apparatus comprises a heating element, 3, a temperature sensing device, 4, located downstream of the heater, means, 5, for modifying the output from the temperature sensing device, 4, and means to measure the frequency of oscillation. The temperature sensor, 4, may comprise a thermocouple or a resistance thermometer, for instance a platinum resistance thermometer. The heating element may comprise any body offering resistance to the flow of electric current and could, for example, be a metal wire of straight form or in the form of a coil or of a coiled coil. The circuit means, 5, takes its input from the sensor, 4, and delivers output to the heater, 3, and would typically include an amplifier to increase the amplitude of the signal from the sensor sufficiently to ensure that oscillation can take place and means to measure the frequency of oscillation. In addition the circuit means, 5, would include at least one of the following:

(a) means to ensure that the voltage signal applied to the heater has a suitable mean level;

(b) means to produce a square voltage waveform which oscillates between suitable voltage levels;

(c) means to provide and modulate a relatively high-frequency carrier wave and a transformer to couple the modulated carrier to the heater;

(d) means to halve the frequency of oscillation.
The sensor, 4, is located in the thermal wake of the heater, 3, and is thus responsive to the power dissipated in the heater. A closed loop which can oscillate is thus formed comprising the sensor, 4, the electronic circuitry, 5, the heater, 3, and a travelling thermal wave downstream of the heater.

In a preferred form of this apparatus, which is illustrated in Figure 4, there is provided means to compensate for the mean temperature of the fluid flowing over the sensor, 4, which might otherwise interfere with the proper operation of the circuit means, 5. In this preferred form there is provided, in close proximity to the sensor, 4, a second temperature measuring device, 7, of considerably greater thermal capacity than the sensor, 4. Because of its greater thermal capacity, sensor 7 is responsive only to the mean temperature of the flowing fluid whereas the sensor, 4, is responsive to the mean temperature and also to fluctuations of temperature of the flowing fluid. Sensors 4 and 7 are connected to the electronic circuitry, 5, in such a way that only the voltage fluctuations are amplified. Conveniently, if the temperature sensor, 4, is a thermocouple then the second temperature sensor, 7, may be a more massive thermocouple made from the same metals as the first thermocouple, 4.

In a particularly preferred form of the apparatus, which is illustrated in Figure 5, there is provided means to measure the fluid flow in a pipe which may be in either direction and means to indicate the direction of flow. This form of the apparatus provides two temperature sensors, 8 and 9, situated on either side of the heating element, 3, as illustrated. The sensors, 8 and 9, are suitably connected to the input of the circuit means, 5. If the fluid flow in the pipe, 1, is in the direction of the arrow, 2, then the output signal from 9 is steady and the output signal from 8 is fluctuating and these fluctuations are amplified by 5. If the fluid flow direction is contrary to the direction of the arrow, 2, then the output signal from 8 is steady and the output from sensor 9 contains fluctuations which are amplified by the circuit means, 5. In this particularly preferred form of apparatus the circuit means, 5, includes means to indicate, for example by causing the illumination of one of a pair of lamps, which of the sensors 8 and 9 is giving a fluctuating output signal.

A second embodiment of the invention will now be described with reference to Figure 6. The illustrated apparatus is intended for the measurement of wind speed. The apparatus comprises a heating element, 10, a temperature sensing device, 11, and circuit means, 12, for

modifying the output from the sensor, 11, and for measuring the frequency of oscillation. The temperature sensor, 11, comprises a resistance thermometer formed of one or more circular loops of wire terminating at 13 and 14 and maintained in a substantially horizontal plane by suitable supports which are not shown in the figure. The heating element, 10, is preferably of elongate form and is supported at the centre of the loop sensor, 11, in a substantially vertical direction. The circuit means, 12, takes its input from the terminals, 13 and 14, of the sensor and delivers output to the heating element, 10, and comprises the circuitry necessary to enable oscillation to occur. Part of the sensor, 11, is located in the thermal wake of the heater, 10, and it is thus responsive to the power dissipated in the heater. A closed loop which can oscillate is thus formed comprising the sensor, 11, the electronic circuitry, 12, the heater, 10, and a travelling thermal wave downstream of the heater. The frequency of oscillation is related to the local wind speed. The apparatus can indicate the speed of air movements in any direction which is approximately horizontal.

CLAIMS

1. Apparatus for measuring the flow speed of a fluid comprising an electric heater situated in the flowing fluid, one or more electrical temperature sensors situated wholly or partly downstream of the heater so that temperature variations in the heated wake downstream of the heater are converted into electrical signals, electronic means to modify signals which takes input from at least one temperature sensor and delivers output to the heater, measurement of the frequency of oscillation of the output signal from the temperature sensor or sensors and electronic means to convert the measured frequency of oscillation into an analogue or digital representation of the flow velocity of the heated wake downstream of the heater.

2. Apparatus for measuring the volumetric flow rate of a fluid flowing in a duct comprising an electric heater situated in the flowing fluid, two sets of one or more electrical temperature sensors situated on either side of the heater so that one set is wholly or partly downstream of the heater when the flow is in one direction and the other set is wholly or partly downstream of the heater when the flow is in the other direction so that temperature variations in the heated wake downstream of the heater are converted to electrical signals by one set of sensors, electronic means to modify signals which takes input from at least one temperature sensor and delivers output to the heater, measurement of the frequency of oscillation of the output signal from the temperature sensor or sensors which are downstream of the heater, electronic means to convert the measured frequency of oscillation into an analogue or digital representation of the flow rate in the duct and to indicate the direction of flow.

3. Apparatus as claimed in any preceding claim wherein the temperature sensor or sensors are thermocouples or thermistors or things which offer a temperature-dependent resistance to the flow of electric current.

4. Apparatus as claimed in claim 3 wherein the electronic means to modify signals is an electronic circuit in which the output is formed by the algebraic addition of the amplified input signal and a steady voltage.

5. Apparatus as claimed in claim 4 wherein the amplification is non-linear.

6. Apparatus as claimed in claim 4 and 5 wherein the amplification is performed by a comparator.

7. Apparatus as claimed in claim 3 wherein the electronic means to modify signals is an electronic circuit in which the output voltage waveform has a fundamental frequency one half that of the input signal and a mean voltage level which is substantially zero.

8. Apparatus as claimed in claim 5 wherein the electronic means to modify signals is an electronic circuit the voltage output waveform of which is a relatively high frequency oscillation the amplitude of which is modulated by the amplified input signal.

9. Apparatus as claimed in any preceding claim in which the electronic means to modify signals is a computer.

10. Apparatus as claimed in claim 8 wherein the modulated high frequency signal is coupled to the heater using a transformer.

11. Apparatus according to any of claims 3 to 9 constructed in the form of a probe for the determination of fluid flow speed and flow direction in pipes and ducts.

12. Apparatus as claimed in any preceding claim for use in measuring the flow of explosive gasses.

13. Apparatus as claimed in any preceding claim for use in measuring the gas flow from landfill sites.

14. A method of measuring the flow speed of a fluid comprising the steps of producing a travelling thermal wake in the flowing fluid downstream of an electric heater immersed in the flow, detection of temperature variations in the heated wake downstream of the heater by means of a temperature sensor having an electrical output signal related to its temperature, modification of the output signal from the temperature sensor by electronic means, application of the modified signal from the temperature sensor to the heater, measurement of the frequency of oscillation of the closed loop system comprising the temperature sensor, the electronic means, the heater and the thermal wake downstream of the

heater, and calculating the flow speed of the flowing fluid from the oscillation frequency of the closed loop system.

Patents Act 1977 **Examiner's report to the Comptroller under Section 17 (The Search report)** 16	Application number GB 9505706.3
Relevant Technical Fields (i) UK Cl (Ed.N) G1N (NACDT, NAEQ) (ii) Int Cl (Ed.6) G01F 1/704, 1/708; G01P 5/10, 5/12, 5/18	Search Examiner M G CLARKE Date of completion of Search 7 JUNE 1995
Databases (see below) (i) UK Patent Office collections of GB, EP, WO and US patent specifications. (ii) ONLINE: WPI	Documents considered relevant following a search in respect of Claims :- 1 TO 14

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Category	Identity of document and relevant passages		Relevant to claim(s)
X	GB 1422685	(POLSKA AKADEMIA NAUK ZAKLAD ETC) whole document	1, 3, 14
X,P	WO 94/15180 A1	(LANG APPARATEBAU) whole document	1, 3, 14

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